Decision Systems Redux

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Abstract

Looking forward, the goal of this article is to stimulate discussion and encourage novel, even radical thinking about computerized systems, especially decision systems including decision automation and decision support systems. Looking back 60 years, this article reviews definitions and articles related to the decision system concept and associated terms like automated decision system (ADS) and decision support system (DSS). This historical perspective differentiates and expands the phenomenon of a decision system to create a modern context for future applied and scholarly research and development. Looking forward, more automated decision systems will make and implement decisions. Analytics will be embedded in decision systems, decision support will proliferate, and decision systems will be part of ambient intelligent environments. Finally, computational organization research (Gasser, 1995) may expand the boundaries of computerized decision systems, help develop and test richer theory, and hence help us better understand organizational decision-making and behavior. This article expands the horizon for decision-making research by reviving the concept of a decision system. Perhaps this article will lead researchers to study decision systems more comprehensively.

Keywords: decision system; decision automation; decision support; decision support system (DSS)

Introduction

Decision system as a concept had its origins in the scientific literature more than 60 years ago, now it seems timely to reassess and potentially revive it. For many years, researchers in Economics, Operations Research, Information Systems, and Management have described, investigated and offered prescriptions to improve decision systems and decision-making. One prescription at the dawn of time-sharing computing was to develop and deploy computerized decision systems, including simulations, and mathematical algorithms. Today increased organizational complexity and massive economic and process changes due to digital transformation create an urgency for a reexamination of decision systems, a conceptual redux. Decision systems should be "revived, brought back, and presented in a new way" as a topic of research and discovery.

This article reflects upon historical research milestones and revives ideas, thought leaders, and technologies related to decision systems to chart a broader, future-oriented research agenda that better leverages our more complex computing and organizational environment. One hopes future academic decision-making, decision science, and information systems researchers develop a sense of perspective and benefit from accumulated knowledge as they seek new, less worn paths.

This article examines and documents how ideas about decision systems evolved into two subtypes of computerized systems variously called 1) decision automation, automated or programmed decision systems, and 2) decision support systems. This narrative also takes a broad view and examines the how and what of decision making and decision systems in organizations.

The study of decision systems has been diverse and diffuse. With origins in the late 1950s, there is an associated problem in understanding the phenomenon because of a poorly documented historical record. Published journal articles and books provide the best available evidence, but we also consulted retrospectives accounts, and recollections about what happened and what was important.

The broad goal of this article is to stimulate discussion about our current knowledge and to identify gaps related to both decision systems as organizational phenomena and as designed and engineered computerized systems. The aspirational goal of this article is to encourage novel, even radical thinking about computerized systems, including analytics, decision systems, decision aids, decision automation, and decision support systems.

Remaining sections 1) define the decision system concept, 2) chronicle and briefly explore historical developments in decision systems from 1960 to 1971, and 3) examine the divergence of the computerized decision system phenomenon to focus almost exclusively on decision support systems that began in the early 1970s. The final sections, 4) examine developing computer-based decision systems, 5) summarize the decision system literature, 6) provide a more forward-looking perspective on decision systems and decision support, and 7) offers some conclusions.

Defining the Decision System Concept

Early uses of the term decision system appear in Dutton (1962), Cyert and March (1963) and Moran (1963). Dutton (1962, p. 21) noted that the total decision system of a business firm includes decisions by machines as well as by men. In the business research literature, Cyert and March (1963) described a complex decision process with multiple decision makers as a decision system. They explained conditions that determined when a decision system is viewed as adaptive. In their analysis, a firm or organization is a decision system. Also, Cyert and March developed two computer models of business decision-making in a firm and compared results from the models with actual results. They concluded that the models had good predictive power. In another early contribution, Moran (1963, p. 26) discussed "development of a practical media decision model which grew out of disillusionment with linear programming." He noted the "process is comprised of the usual major components: Data Input and the Decision System" (p. 29).

One should discuss the decision systems of an organization in terms of the people, processes, systems, and data. Often this term has been used too narrowly, referring only to computer-based programs and technologies intended to make routine, structured decisions, monitor and control processes, and assist decision makers in well-defined, semi-structured decision situations.

The DSSResources.com glossary defines a decision system as a general term that includes both decision automation and decision support systems (DSS). This view is derived from Simon (1960) and Gorry and Scott Morton (1971). Figure 1 is a prescriptive matrix for deploying computerized decision systems.

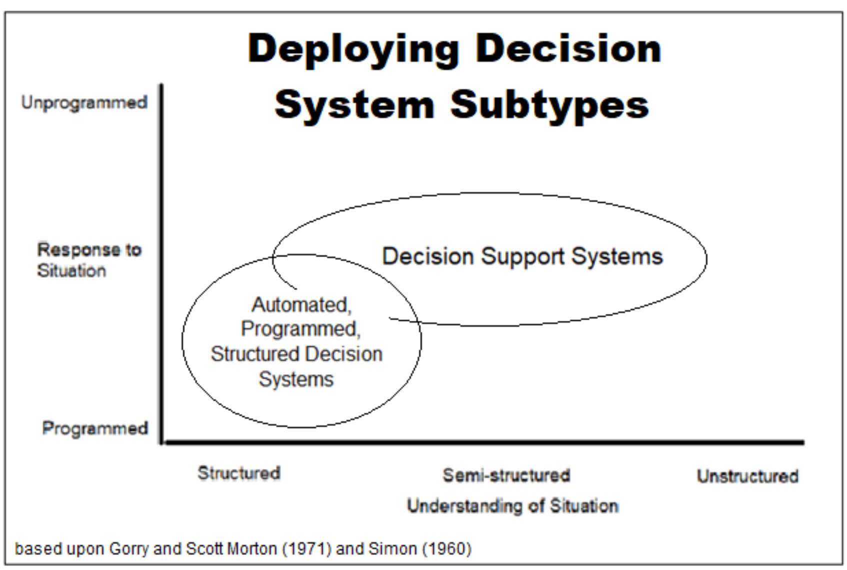

Figure 1. Decision Systems Continuum

Overall, a decision system is a set of interacting people, methods, procedures, programs, and routines for making decisions or supporting decision processes.

Promotional materials at researchgate.net for the Journal of Decision Systems (JDS) note “decision systems refer to computer-based applications that can replace (partially or totally) or help individuals or groups in their decision-making tasks”[1].

Gerrity (1970), in his Ph.D. dissertation at MIT Sloan School of Management, defined a man-machine decision system (MMDS) “as involving the interaction of three main components: 1. man - the decision maker (one or more); 2. machine - meaning a computer, plus associated information technology necessary to support man-computer interaction; and 3. decision task - the problem, plus related environment and information sources” (p.11).

Related terms are decision automation system (DAS) and automated decision system (ADS). These synonyms more narrowly refer to a rule-based knowledge system that makes a choice among predefined solutions using specified inputs for a specific, repetitive decision task. The rules and analytical, especially predictive, models provide the decision logic for an ADS. In many ADS, forecasting and optimization algorithms provide inputs to rules based upon external inputs. There are many use cases for ADS; they may automate pricing decisions, approve loans, or make stock trades. Davenport and Harris (2005) identify a number of automated decision system technologies, including data mining and rule engines. They explain “Data mining allows people to use sophisticated algorithms and search engines to find patterns and correlations in large, pre-existing databases. Rule

[1] https://www.researchgate.net/journal/1246-0125_Journal_of_Decision_System

engines process a series of business rules using conditional statements to solve non-algorithmic problems”.

Increased capability of information technology now allows many decision tasks to be performed by algorithms and computer programs like enterprise resource planning (ERP). Technological development has also expanded the reach of decision support applications and their range of use. For instance, using wireless networks, a decision system may be embedded in an Internet of Things (IoT) device, part of an Ambient Intelligence (AmI) environment, or accompanying a person using a wearable or hand-held device.

Historical developments -- Formative years 1960-1971

An influential, ground-breaking decision system conceptual article by J. C. R. Licklider (1960) envisioned man-computer symbiosis "to enable men and computers to cooperate in making decisions” (p. 4). Licklider explained "one of the main aims of man-computer symbiosis is to bring the computing machine effectively into the formulative parts of technical problems. The other main aim is closely related. It is to bring computing machines effectively into processes of thinking that must go on in 'real time,' time that moves too fast to permit using computers in conventional ways. ... men will handle the very-low-probability situations when such situations do actually arise. ... the computer will serve as a statistical-inference, decision-theory, or game-theory machine to make elementary evaluations of suggested courses of action whenever there is enough basis to support a formal statistical analysis" (p. 5). Licklider was the architect of Project MAC at MIT that furthered the study of interactive computing.

Herbert Simon's landmark book **The New Science of Management Decision** (1960) clearly influenced early research in decision systems and decision support. Simon explored programmed decision making and noted

> "simulation has enabled an airline to determine how many reserve aircraft it should keep on hand, has been used to study highway congestion, has led to improvement in inventory control procedures for a huge warehousing operation, and has accomplished many other difficult tasks. (p. 19) … The revolution in programmed decision making has by no means reached its limits, but we can now see its shape. The rapidity of change stems partly from the fact that there has been not a single innovation but several related innovations, all of which contribute to it" (p. 20).

In a 1963 Engineering Management article, Andrew Vazsonyi used the Program Evaluation and Review Technique (PERT) with an on-line man-machine system to help a manager examine a wide array of alternative solutions. Vazsonyi concluded that with the aid of the man-machine system a "manager will be able to examine a wide panorama of suboptimum alternatives and will arrive at a better decision than is possible today" (p. 156).

Pioneering work of George Dantzig and Jay Forrester influenced the feasibility of building computerized decision systems. Dantzig' s simplex algorithm for solving linear programming optimization problems was a major break-through. Dantzig worked on a number of U.S. Government projects, and then at the Rand Corporation where he began implementing linear programming for computers. Gass (2002) reviews Dantzig's contributions and notes "By having linear-programming simplex-based method codes, the early electronic computers were transformed into catalysts for generating new and important OR applications" (p.66). According to other colleagues of Dantzig (i.e., Gill, Murray, Saunders, Tomlin, and Wright, 2007), "Given the limited computing power available during the 1940s and 1950s, there was no possibility then of solving “realistic” systems-scale linear programs, meaning those with thousands of inequalities and unknowns. But by the 1960s, progress in hardware, algorithms, and software meant that some linear programming problems of this scale could be solved in a reasonable time on existing computers.” (p. 152).

Forrester was involved in building the Whirlwind digital computer for experimental development of military combat information systems. The Whirlwind computer was used for the SAGE (Semi-Automatic Ground Environment) air defense system for North America completed in 1962. According to Forrester (l989), the SAGE system had about 35 control centers, each 160 feet square, four stories high, and containing about 80,000 vacuum tubes. SAGE is probably the first computerized data-driven decision system. Also, Professor Forrester started the System Dynamics Group at the Massachusetts Institute of Technology Sloan School. His work on corporate modeling led to developing DYNAMO, a general simulation compiler.

By April 1964, the development of the IBM System 360 and other more powerful mainframe systems made it practical and cost-effective to develop Management Information Systems (MIS) for large companies (cf., Davis, 1974). These early MIS focused on providing managers with structured, periodic reports and the information was primarily from accounting and transaction processing systems. These systems did not provide interactive support to assist managers in decision making.

In the mid-1960s, actually developing computer-based decision systems became more feasible because of advances in IT processing capability and increased computer memory. Miller, Kaplan, and Edwards (1967; 1969) reported evaluations of a computer-assisted decision technique called JUDGE (Judged Utility Decision GEnerator) written using the SIMSCRIPT language (Markowitz, Hausner, and Karr, 1962). The JUDGE system was "designed to dispatch aircraft on non-preplanned close air support missions, the number dispatched depending on judgments of target values made by experts at the times when targets appear” (p. 97). The results confirmed the superiority of the computer-assisted decision system, JUDGE, over a conventional system in dispatching close air support missions.

Simulation can also help understand decision systems in firms. Bonini (1963) developed a simulation of a hypothetical business firm. Their complex and detailed model was programmed in FORTRAN and run on an IBM 7090 computer, a second-generation transistorized scientific computing system. The simulation involved defining decision centers, information centers, and decisions rules. Bonini explains "A decision system is the sum total of all the decision rules in the organization. Thus, a specific decision system means a specific set of decision rules (including specified decision parameters)” (p. 18). Bonini specified complex behavioral decision rules for the simulation. The firm in the simulation had three major areas: manufacturing, sales, and an executive committee for planning and control of the whole firm.

There were concerns about automation as well. Cyberneticist Stafford Beer noted in 1966 that “The computer will replace the manager only in those functions which the manager (aided by science) is able to elucidate. The class of judgments which the manager is able to elucidate continuously grows. … But that machines should one day, in the long run, outclass the intelligence of their designers is not only possible but virtually guaranteed” (p. 445).

What was occurring? In 1966, Winer explained that as “marketing activities have grown more complex, it has become difficult to relate individual marketing decisions to the basic profit objective” (p. 38). In his article "A Profit-oriented Decision System", he proposed including "financial" criteria in marketing management decisions. He notes "It is the purpose of this article, therefore, (1) to present a marketing-decision system that is based on the return-on-investment concept, and (2) to show how this system may be applied by marketing managers to many kinds of decision problems” (p. 38). This article did not report on a computer-based system, but it was around this time that people were thinking about creating decision systems.

From a more technical perspective, Edwards, Phillips, Hays, and Goodman (1968) proposed a Probabilistic Information Processing System (PIP). PIP “uses men and machines in a novel way to perform diagnostic information processing. Men estimate likelihood ratios for each datum and each pair of hypotheses under consideration or a sufficient subset of these pairs. A computer aggregates these estimates by means of Bayes' theorem of probability theory into a posterior distribution that reflects the impact of all available data on all hypotheses being considered” (p. 248). In a large simulation-type experiment, PIP performed better than human operators at aggregating information.

Ackoff (1967) prescribed analysis and detailed examination of the organization decision system prior to designing a management information system. He considered failure to analyze the decision system as a contributing factor in providing misinformation and creating information overload. Pfiffner (1960) argued "the information system and the decision system are interdependent and both are circular and multi-dimensional” (p. 130).

These seminal articles describe the symbiotic nature of the relationship between decision systems and IS/MIS.

Further, Dickson (1968) in an article titled “Management information-decision systems: A new era ahead?” explained the “sheer size and complexity of today's vast business conglomerates require a new technology to cope with the problems of administration. Such a technology is being developed: management information-decision systems. This new discipline is emerging to integrate other techniques and to provide the analytical frames of reference and the methodologies necessary to meet the new management requisites” (p. 17).

Two important articles by Kriebel (1969) and Ferguson and Jones (1969) related to decision systems were published in the journal Management Science. Kriebel reported on research by the Management Sciences group at Carnegie-Mellon University in an article titled “Information processing and programmed decision systems.” Kriebel suggested “some practical extensions of the decision theory model for the design of management information processing systems and to illustrate these ideas through the detailed analysis of an aggregate planning problem” (p. 149).

Ferguson and Jones (1969) developed an on-line, real-time, time-sharing model of a job shop so users could explore various combinations of heuristics and programmed decision rules for production planning. In their study, over 300 managers and academicians assumed the role of managers and participated in experiments with the prototype system that demonstrated its practicality to aid in decision making and problem solving. They investigated a production scheduling application running on an IBM 7094.

Also in 1969, Schrenk proposed aiding decision makers in an IEEE Transactions on Man-Machine Systems article. He explained that “Despite an increasing capability for automating various tasks there continues to be a requirement for man to serve as the decision element in many complex systems. The complexity and far-reaching consequences of many decisions impels a concern for improving decision-making performance in man-machine systems” (p. 204).

Janssen (1970) described and explained a project to develop an information-decision system for bank reserve management. The system integrated a forecasting model and a dynamic programming decision model.

In 1971, Sprague published a conceptual description of a planning model that was central to an integrated computer-based planning system. The planning model used a linear programming algorithm "to optimize 'balance sheet management' decisions within liquidity and capital adequacy constraints" (p. 66).

According to Sprague and Watson (1979), around 1970 business journals started to publish articles on management decision systems, strategic planning systems and decision support systems.

Differentiating the Computer-based Decision System Phenomenon

Michael Scott Morton’s early work formed the basis for the field of Decision Support Systems: the use by managers of interactive computer systems to support their decision-making. In a 2007 email interview (cf., Power, 2007), Scott Morton discussed how he became interested in this research area. Scott Morton explained

> “Time sharing computing had just become available to me as a student at Carnegie-Mellon University (Carnegie Institute of Technology as it then was) in 1959. The

> whole concept of putting computing power in the hands of the user was exciting. It represented to me a potentially powerful new tool for humans to use in their work. At the time I was working on several projects for my Professors (Herb Simon and Hal Leavitt) which got me exposed to research on human decision processes."

In 1971, Michael S. Scott Morton's ground-breaking book **Management Decision Systems: Computer-Based Support for Decision Making** was published by the Harvard Business School Press. The book was largely Scott Morton's doctoral dissertation (Harvard Business School, June 1967). In 1966-67 Scott Morton had studied how computers and analytical models could help managers make a key decision. He conducted an experiment in which managers actually used a Management Decision System (MDS). Marketing and production managers used an MDS to coordinate production planning for laundry equipment. MDS ran on an IDI 21 inch CRT with a light pen connected using a 2400 bps modem to a pair of Univac 494 systems.

In the interview (Power, 2007), Scott Morton explained his classification of decisions and the potential for computerized decision support. He noted "my research did establish clearly the fact that for the correct class of decisions, computerized systems could have a major beneficial impact on both the decisions and the decision processes of managers."

Scott Morton's (1967) dissertation research was a pioneering implementation, definition and research test of a model-driven decision system. Gordon Davis in a 2003 email[2] that commented on the history of decision support systems wrote in part

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[2] Mon, June 8, 2003, email is in appendix of http://dssresources.com/history/dsshistoryv28.html

> “my frame of reference views management decision support as a natural outgrowth of the intellectual foundations of management information systems. Operations Research, Management Science, Simon’s work on management, and the Anthony taxonomy undergird the design of systems to support management. The question is why DSS became identified as a separable body of work? It is probably because the availability of time sharing, terminal-based systems, PCs, and networked systems plus the availability of improved repositories of data made decision support a rich area of development and research.”

What was occurring? T. P. Gerrity, Jr. focused on design issues in his 1971 Sloan Management Review article titled "The Design of Man-Machine Decision Systems: An Application to Portfolio Management". The article was based on his MIT Ph.D. dissertation. His system was designed to support investment managers in their daily administration of a clients' stock portfolio.

John D.C. Little, also at Massachusetts Institute of Technology, was studying decision and planning systems for marketing. Little and Lodish (1969) reported research on MEDIAC, a media planning support system. Also, Little (1970) identified criteria for designing models and systems to support management decision-making. His four criteria included: robustness, ease of control, simplicity, and completeness of relevant detail. All four criteria remain relevant in evaluating decision aiding and decision support systems.

The first use of the term decision support system was in Gorry and Scott-Morton’s (1971) Sloan Management Review article. They argued that Management Information Systems primarily focused on structured decisions and suggested that the supporting information systems for semi-structured and unstructured decisions should be termed “Decision Support Systems”.

In 1974, Gordon Davis, a Professor at the University of Minnesota, published his influential text on Management Information Systems. He defined a Management Information System as "an integrated, man/machine system for providing information to support the operations, management, and decision-making functions in an organization" (p. 5). Davis's Chapter 12 was titled "Information System Support for Decision Making" and Chapter 13 was titled "Information System Support for Planning and Control". Davis's framework incorporated computerized decision support systems into the emerging field of management information systems.

Peter Keen and Charles Stabell claimed that the concept of decision support systems evolved from "the theoretical studies of organizational decision-making done at the Carnegie Institute of Technology during the late 1950s and early '60s and the technical work on interactive computer systems, mainly carried out at the Massachusetts Institute of Technology in the 1960s" (Keen and Scott Morton, 1978).

Donovan and Madnick (1977) distinguished among 1) structured decision systems, that assess routine, recurring, well-structured decision situations, 2) institutional DSS, that assess less-structured decisions of a recurring nature, and 3) ad-hoc DSS, that assist with unanticipated or non-recurring decisions. They defined the term decision support system (DSS) as a subset of management information systems that truly support decision-making processes. DSS only included ad-hoc and institutional applications.

Starting in the 1970s, both practice and theory issues related to decision systems and DSS were discussed at academic conferences including the American Institute for Decision Sciences (AIDS, now known as DSI) founded in 1969. IFIP Working Group 8.3 on Decision Support Systems was founded in 1981. The first International Conference on

Decision Support Systems (ICDSS) was held in Atlanta, Georgia in 1981. Academic conferences provided forums for idea sharing, theory discussions and information exchange.

In 1980, Steven Alter published his MIT doctoral dissertation results in an influential book titled Decision Support Systems: Current Practice and Continuing Challenge. Alter's research and papers (1975; 1977) expanded the framework for our thinking about management decision systems.

Bonczek, Holsapple, and Whinston (1981) created a theoretical framework for understanding the issues associated with designing knowledge-oriented Decision Support Systems. Their book showed how Artificial Intelligence and Expert Systems technologies were relevant to developing DSS. Ralph Sprague and Eric Carlson’s (1982) book **Building Effective Decision Support Systems** elaborated on the Sprague (1980) DSS framework of data base, model base and dialog generation and management software.

Decision systems often involve groups of interacting people. In the 1980s, DeSanctis and Gallupe (1987) extended the boundary of computerized decision support to include an information-exchange perspective. While traditional DSS were intended to help individual decision makers, GDSS were targeted at supporting groups of senior managers and other professional groups in complex group decision making scenarios (Gray, 1987).

GDSS technology ranged in complexity from group communication and collaboration features, including option selection functionality, to “sophisticated rule-based systems that enable a group to pursue highly structured and novel decision paths” (DeSanctis and Gallupe, 1987, p. 589). At that time, GDSS were explored mostly in decision laboratory and experimental environments (Nunamaker et al., 1987). GDSS technology enabled enhanced collaboration across geographically dispersed teams. In the 1990s, the terms computer-mediated communication (CMC) and computer supported cooperative work systems (CSCW) were introduced to characterize technologies used to support group communication in virtual teams and face-to-face group decision making. In the academic literature, GDSS, CMC and CSCW are sometimes used interchangeably, and arguably all of these components can be included in decision systems.

Developing Computer-based Decision Systems

Technology progress has facilitated the development of more sophisticated decision systems. While structured, programmed decision systems can provide valuable automation so people without the required expertise can run a program to make decisions, building these systems using conventional programming approaches was challenging. A decision-maker expert must establish the decision criteria and principles that are turned into a computer program design for implementation by a programmer who likely does not have any knowledge of the decision domain. Finally, the finished program must be extensively tested. If any changes are subsequently required, the same process of going back to the programmer is needed and this encourages development of decision systems for problems which are routine, recurring and stable over time.

Because of the difficulties of building programmed decision systems, decision system research developed several alternative approaches to bypass these challenges. These approaches take advantage of improvements in the performance of information technology. Expert systems (Luconi, Malone, Scott-Morton, 1986) separate the decision rules from the program logic and provide a general-purpose tool that can be used with different domain specific rule sets for different decisions. Expert systems still require the careful development of the decision rules, which requires the time of the expert, but the technical implementation of the system is then much easier.

Case-based reasoning (CBR) makes or supports decisions by looking at previous examples and using the same approach as the most similar successful example (Aamodt & Plaza, 1994). CBR requires a large case base of previously solved problems, but when this has been built the system can then run without much intervention. As new successful cases are stored in the case base, CBR improves over time if there are no dramatic changes in the problem domain. CBR does not require direct input from experts.

Machine learning allows decision principles to be identified from previous records containing quantitative information. Machine learning is a form of pattern recognition, where common patterns can be identified for desirable and undesirable outcomes then the computer can derive machine rules based on these patterns to better achieve the desirable outcomes. For instance, machine learning can identify the common characteristics of good customers and establish decision rules for the customers who should receive discounts. Machine learning techniques are also widely employed in fraud detection, being able to derive rules that can reduce the proportion of fraudulent transactions. Machine learning is relatively computationally intensive and has flourished in recent years as computers have become more powerful. The ability of machine learning to establish decision rules without labor intensive involvement by experts makes it the basis of many modern decision systems and this number will only grow in the future.

Summarizing the Decision System Literature

Much has been written about decision systems, in particular computerized decision support systems. Citation databases such as Web of Science (WOS) allow the identification widely cited articles. The CitNetExplorer software (van Eck & Waltman, 2014, 2017) allows the visualization of key publications. Figure 2 shows key papers relating to decision support and decision systems. Those colored blue are widely recognized as central to the field. On the left are articles, colored green in this figure, representing Multi-Criteria Decision Analysis (MCDA) research. MCDA is one of the most widely used decision structuring techniques in decision systems. Those articles colored orange represent the environmental disciplines and Spatial Decision Support Systems. Jones, on the left, is an important author in agricultural DSS. Those colored pink to the right of the core papers represent Case-based Reasoning. The papers on the far right of the figure are from the medical field and include Clinical DSS (CDSS).

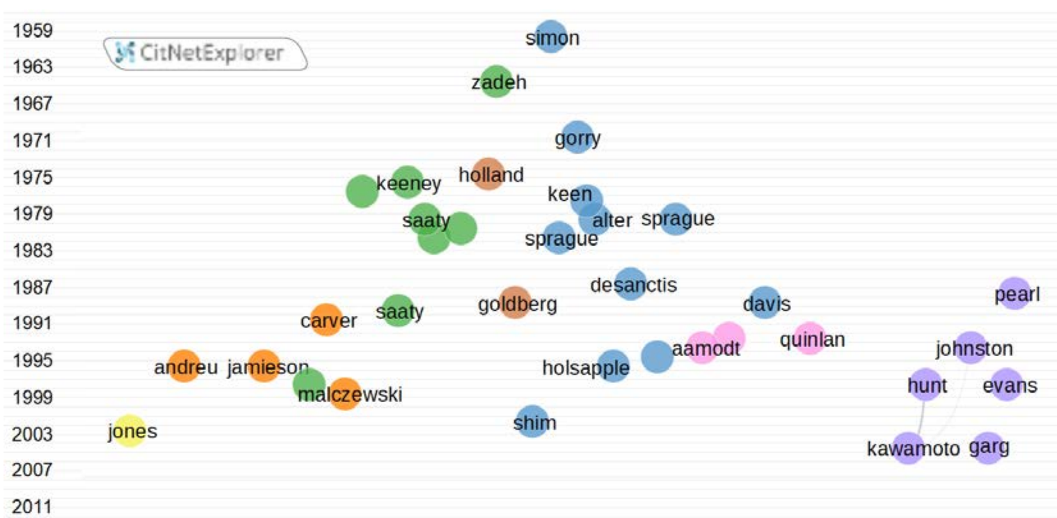

Figure 2. Important DSS related papers visualized in CitNetExplorer

In general, the left and right wings of Figure 2 represent two distinct growing areas of decision systems, the environmental and medical disciplines (Keenan, 2016), which are somewhat disconnected from the traditional decision system/decision support field.

There have been many developments related to decision systems since the early 1960s that are illustrated in Figure 3. The diagram is not exhaustive, but it highlights the main innovations in Decision Systems (positioned in the top half of the diagram) while depicting the pivotal advances in technology occurring in parallel (illustrated in the lower part of the diagram). It is noteworthy that some of the most novel and progressive ideas were conceptualized and shared by scholars in the area of MIS/Decision Systems prior to the availability of the sophisticated technology required to realize their ambitions. For example, the concept of Artificial Intelligence (AI) has existed for more than fifty years. It is only recently that advances in hardware and software has allowed us to harness the potential of AI in a diverse range of industries including healthcare, financial services, manufacturing and retail.

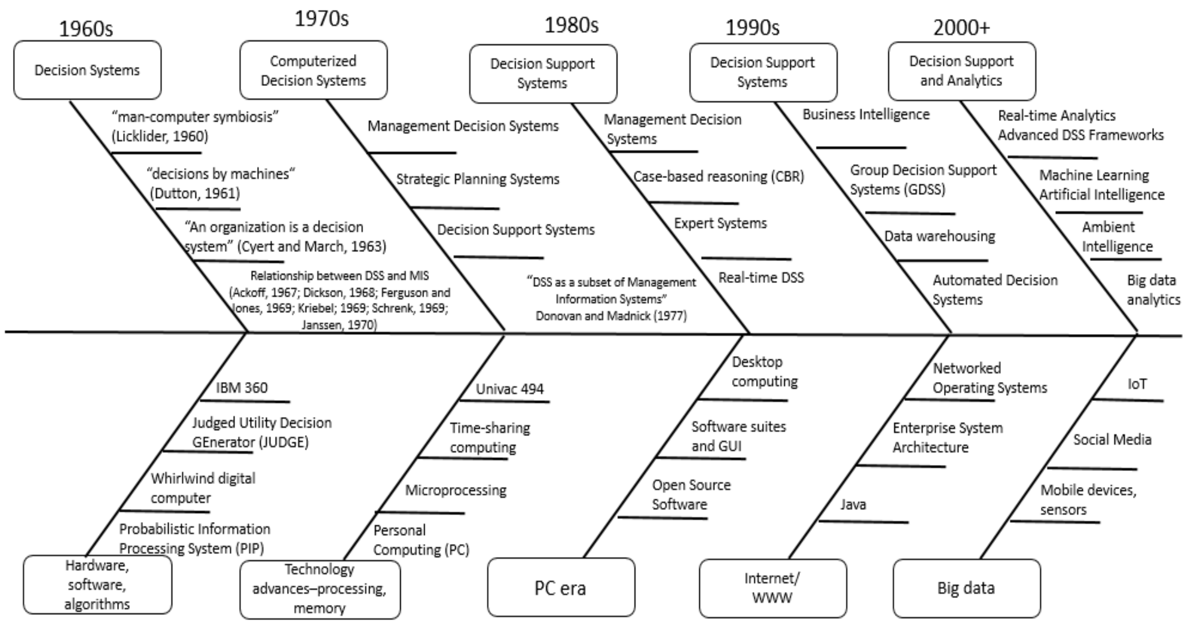

Figure 3. Advances in Decision Systems and Technology

In 1995, decision support and decision systems entered the Internet and World-wide web era. A few years later, Power (2000; 2002; 2004) proposed an expanded Decision

Support Systems framework that specified a primary technology dimension that provides decision support. Three secondary dimensions in the framework are the targeted users, the specific purpose of the system and the primary deployment technology. Five generic DSS types were identified and defined: 1. Communications-Driven DSS, 2. Data-Driven DSS, 3. Document-Driven DSS, 4. Knowledge-Driven DSS, and 5. Model-Driven DSS.

Looking Forward

Much has occurred in the field of decision systems in 60 years. In recent years, real-time decision systems, big data analytics, and ambient intelligence (AmI) decision systems have become feasible. While this is not a new concept, improved technology means that real-time decision systems are increasingly important. Thierauf wrote a number of books (1975, 1982) that dealt with on-line, real-time MIS and DSS. He explained in 1982 that "any system that processes and stores data or reports them as they are happening is considered to be an on-line real-time system" (p. 20). Real-time systems respond within a specified time constraint. There is no appearance of delay in the responses. What is new is more sophisticated Artificial Intelligence (AI) tools and development capabilities for systems.

Real-time decision support and decision systems are sometimes desirable and are needed in the following situations: 1) both the decision-maker and organization can benefit; 2) the system improves understanding rather than increasing information load, 3) the system is cost-effective, and 4) real-time data and information make a difference in decision making, and often results in better outcomes. Current evidence suggests real-time decision systems, decision support, and data analysis is critically important for some operational decisions.

Real-time decision systems and real-time decision support require large quantities of streaming, real-time data, fast processing, and excellent communications. Common big data sources for real-time processing, include social media, mobile device files, knowledge data stores, machine logs, and sensor analytics. Activity-generated data primarily comes from computer and mobile device log files (cf., Morris, 2012), especially with time and location stamping.

Mobile devices, wearable technology, connected devices, sensors, social media, loyalty card programs and website browsing history are generating large volumes of useful structured and unstructured data. As Beer (1966) predicted, decision automation is replacing managers for well-defined structured decision tasks. An algorithmic decision system makes and implements decisions. Sensors and databases provide the inputs for an algorithm to process.

Technology innovation and advancement is creating opportunities for even more ambitious decision systems that are part of Ambient Intelligence (AmI) environments. Ambient Intelligence (AmI) refers to a data-intensive environment controlled by software that senses changes in state and responds appropriately to correct, act or alert decision makers. The goal of a sensor-rich AmI environment is stability and homeostasis. AmI environments include Artificial Intelligence and sensors.

Ambient intelligence (AmI) refers to any digitized living and working environment designed with embedded technology and AI to assist people. Ambient describes a physical space and its internal and external surroundings. Ambient intelligence (AmI) is a capability for a pervasive computing environment that enables interaction with and appropriate responses to the people in that specific environment.

Using analytics, decision support and AI deployed in a secure local area network connecting "smart" devices, an AmI environment may include decision automation and decision support systems. An AmI environment may interact directly with the people who are working or living in that environment.

At a fundamental level, the hope has always been that our information and decision support systems would help decision makers and computer software monitor events, and evaluate, choose and act on alternatives as events actually unfold. The programmed decision making of Simon (1960) and discussions of man-machine symbiosis envisioned fitting decision tasks to both man or machine, and machine assisting or helping man as appropriate. More powerful computers and improved techniques have allowed decision systems exploit relatively complex structured problems, which required human input when this computing power was not available in earlier decades. Consequently, the range of automated systems has expanded and this process will continue. However, the range of decisions is enormous and many other types of decisions will still use computerized decision support. In particular, the range of decisions goes beyond the traditional business domain to include areas such as environmental and medical applications which may be less easily automated. Business vendors will always take an interest in high volume, understandable systems, which sell best, but academics can usefully research novel systems in more specialized areas. Decision research needs to address this larger canvas. However, one issue in the fragmentation of the field is that new methods and new decision-making paradigms may not be quickly disseminated in a more diverse research community. We challenge academics and researchers to leverage innovative and novel means to share, collaborate and promote their descriptive and prescriptive decision-making research and development activities and results to reach broader community of decision behavior and augmentation experts.

Even for largely automated systems there will always be exceptions which need human intervention. Therefore, a system might be 95% automated with humans helping direct the more complex sophisticated cases. One issue is the transition from the automated to the human. An extreme example would be Air France 447 or the recent Uber automated car crash when the automated system handed back to the human who was not able to quickly figure out what to do. Few decision systems make life and death decisions, but researchers should investigate the difficult question of how to incorporate human guidance into a largely automated systems that make consequential decisions.

Much of the seminal DSS theory has been developed within the context of limited technological capabilities and in some cases no technology at all. Business vendors emphasize the technology and downplay the need for proper theories and decision models to direct the use of that technology. And other areas of DSS application have much less mature technologies than traditional business applications. Recent advances in technology and the broader canvass for decision making has created a breadth of new opportunities for researchers to draw on new innovative decision support and analytics tools and technologies and leverage existing seminal theory to test, extend and even build new theories. We encourage researchers to undertake empirical studies identifying novel decision scenarios where emerging technologies play an important role.

A major issue discussed in this article is the domain of decision systems. Some researchers have focused on the decision support tools deployed in decision systems, while other researchers have emphasized automating decision systems. Few have looked at the descriptive efforts to simulate decision systems in recent years. We encourage academics and practitioners to consider the Journal of Decision Systems (JDS) as a broad "home" to disseminate articles dealing with the processes, procedures, people, computerized systems, tools and ephemera of structured and semi-structured decision making in organizations.

Conclusions

The goal of this article was to review the concept of decision systems and revive and reinvigorate research related to topics associated with this overarching concept. While decision making remains very important in organizations, opportunities for improving decision making with decision systems, both automated and decision support, have expanded and increased. Figure 3 depicts the main phases in a prescribed and sometimes descriptive organizational decision system based upon the Simon (1960) framework. Herbert Simon (1960) identified three stages in a decision process: Intelligence, Design, and Choice. Organizational decision systems are task and tool-oriented. Phase one is the Intelligence or Issue Identification and Problem Focused phase of a decision system. Organizations are concerned with information gathering and problem identification. At this initial stage in a decision system, managers rely on dashboards of information, undirected searches and descriptive analytics to understand - What is happening? What happened? What has happened?

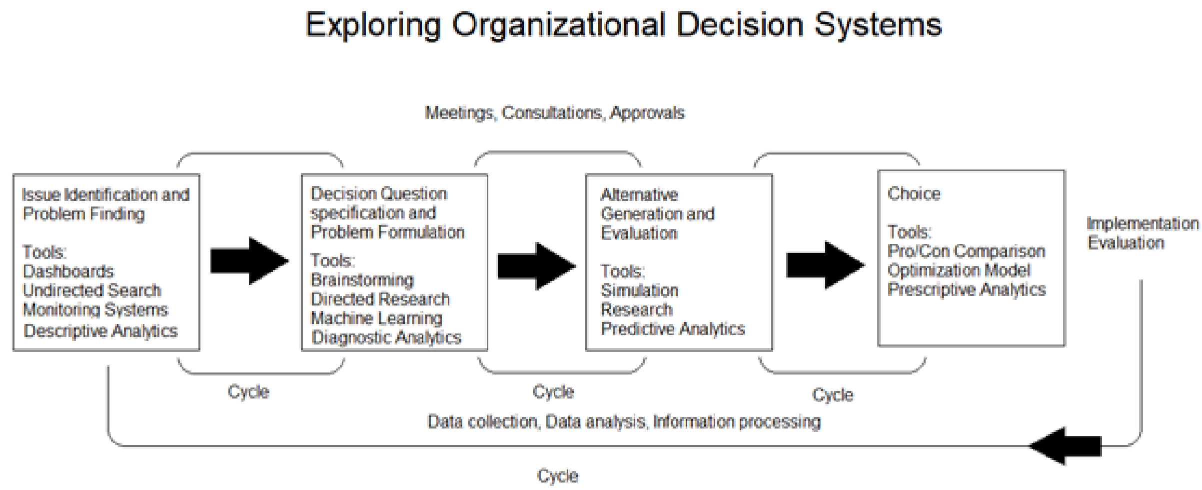

Figure 4. Exploring Organizational Decision Systems (adapted from Simon, 1960)

In Figure 4, we have divided the design phase into two distinct phases, ‘Decision Question Specification and Problem Formulation’ and ‘Alternative Generation and Evaluation’. As part of Decision Question Specification and Problem Formulation phase, managers focus on refining the problem, defining the boundaries of the decision question, and clearly articulating the decision question. Brainstorming, directed research, machine learning and diagnostic reporting are used to help managers find answers to questions such as: What happened? Why did it happen?

During phase three, managers generate alterative decision options, each of these may be evaluated using computer-based simulation technologies and predictive analytics reporting tools guiding managers in their selection of the best alternative and prompting them to ask questions such as: What will happen? What will happen next?

The final phase of a prescribed decision system focuses on choice. This phase involves the decision maker(s) in selecting a course of action. This is often achieved using decision support, ‘what if analysis’, and tools like optimization modeling and prescriptive analytics. During the choice phase, managers ask questions including: What should happen next? What should I do? What should we do? How should we do it?

Decision support may be appropriate in all, one, or none of the four stages illustrated in Figure 4. Managers should take an iterative approach to decision making, revisiting a phase when required. Each decision must be evaluated incorporating feedback into the decision system at every phase. Automated decision systems and decision support systems can incorporate and use one or more of four types of analytics, i.e. descriptive, diagnostic, predictive, and prescriptive, to make and/or support decisions.

This article has reviewed the formative years for decision systems and DSS. The computerized decision system phenomenon is still evolving. One hopes this "redux" creates a modern context for understanding historical developments in decision systems, including automated or programmed decision systems and decision support systems for semi-structured situations.

Future generations of researchers will develop decision systems of increasing complexity and sophistication. The vision, the driving idea of decision systems and the new science of decision making, to create an appropriate symbiosis of man and machine remains relevant and challenging. There are many ethical dilemmas to be confronted in this new era of "big data" and decision making. These ethical issues will lead to legal restriction on certain forms of decision system, for instance the European General Data Protection Regulation (GDPR) (European Union, 2016) states that a "data subject shall have the right not to be subject to a decision based solely on automated processing" (Art 22). New opportunities to use data from real-time devices will be many. Design science, case studies, philosophical explorations, and empirical studies must help resolve the dilemmas of man versus machine and create a beneficial partnership.

Research related to decision systems may develop innovative decision system capabilities using quantitative models or Artificial Intelligence. Experimental research may compare systems or quantitative models. Qualitative research related to in situ organization man-machine decision systems may lead to the development of complex simulations of organizations, i.e., actual functioning decision systems, cf., Bonini, (1963). Computational organization research can help understand organization decision systems and decision making. As Bonini (1962) explained there is a need "for a model or framework that the theorist can use to study the effects of information and related organizational factors upon decision-making in the whole firm" (p.33).

Overall, more knowledge about and innovation related to decision systems, especially automated decision systems, can help create more productive and profitable operations in organizations. Expands the horizon and scope for decision-making research by reviving the concept of a decision system will benefit theory and understanding. Perhaps this review and analysis will motivate researchers to study decision systems more comprehensively.

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